Original Article

Evaluation of the anterior dentoalveolar relationship in skeletal Class III malocclusion patients with different vertical facial patterns using cone-beam computed tomography

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ABSTRACT

Objectives: To measure and compare labiolingual inclinations of the teeth and alveolar bone and the anterior dentoalveolar inclination in patients with skeletal Class III malocclusions with different vertical facial patterns using cone-beam computed tomography (CBCT).

Materials and Methods: Based on the inclusion and exclusion criteria, 84 CBCT images of patients with untreated skeletal Class III malocclusion were selected. There were 28 patients each in the hypo-, normo-, and hyperdivergent groups. The labiolingual inclinations of the teeth, the corresponding alveolar bone, and the anterior dentoalveolar inclinations were measured and analyzed statistically.

Results: The inclinations of the mandibular canine and corresponding alveolar bone were smaller in the hypodivergent group than in the hyperdivergent group. The inclination of the alveolar bone and the maxillary dentoalveolar inclination were smaller in the hyperdivergent group than in the hypodivergent group.

Conclusions: There were differences in the inclination of the teeth, corresponding alveolar bone, and dentoalveolar inclinations at different positions among skeletal Class III patients with different vertical facial patterns. The roots were generally located on the labial side of the alveolar bone. (*Angle Orthod*. 2024;94:187–193.)

KEY WORDS: Dentoskeletal relationship; Skeletal Class III malocclusion; Vertical facial patterns; CBCT

INTRODUCTION

The global incidence of skeletal Class III malocclusion in individuals with permanent dentition is reported to be 5.93%.[1] Adult patients with mild to moderate skeletal Class III malocclusion can choose camouflage treatment to further increase compensatory inclination of the anterior teeth and mask incongruity between the maxilla and mandible.[2,3] However, tooth movement is restricted by the alveolar bone.[4–6] Therefore, it is necessary for orthodontists to understand the characteristics of the dentoalveolar relationship in patients with skeletal Class III malocclusion.

Gracco et al.[7] introduced a cone-beam computed tomography (CBCT) method of describing the position of the upper incisors and proposed that the angle between the incisor, buccal, and lingual cortical axes can be used to evaluate dentoalveolar relationships. Recently, several studies on the buccolingual inclination of the teeth in different positions have been reported; however, the sample populations differed.[8–14] In 2017, Sendyk et al.[14] found that the maxillary incisors and mandibular canines in patients with skeletal Class III malocclusion had greater inclinations than those in individuals with normal occlusion; however, whether vertical facial patterns influenced the results was not discussed. Eraydin et al.[10] found that buccolingual inclinations of the maxillary and mandibular molars were similar among three groups of skeletal Class I malocclusion patients with different vertical facial patterns.

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Table 1. Inclusion and Exclusion Criteria for Sample Selection

Inclusion Criteria	Exclusion Criteria
18–30 y	History of orthodontic treatment
ANB angle of $<0°$	History of restorations, trauma, or surgery in the anterior region
<2 mm of crowding in the maxillary and mandibular anterior regions	Craniofacial syndromes
No obvious wear in the anterior teeth	Abnormal number of teeth in the anterior region
Images suggesting no horizontal or vertical proximal alveolar bone loss	

To date, no studies have compared the differences in labiolingual inclination of the anterior teeth, measured alveolar bone inclinations, or analyzed the dentoalveolar relationship among skeletal Class III malocclusion patients with different vertical facial patterns.

This study aimed to use CBCT to measure and compare labiolingual inclinations of the anterior teeth and corresponding alveolar bone in skeletal Class III malocclusion patients with different vertical facial patterns and further evaluate the dentoalveolar relationship by measuring the dentoalveolar inclination (the angle between the tooth and corresponding alveolar bone axes). The null hypothesis was that no differences would exist in the measured characteristics among skeletal Class III malocclusion patients with different vertical facial patterns.

MATERIALS AND METHODS

This was a retrospective, cross-sectional study. Patients who visited the Orthodontic Department of Tianjin Stomatological Hospital and were accepted to undergo CBCT scans were screened. The criteria for sample selection are listed in Table 1. Power analysis with a 0.25 effect size, $>80\%$ power, and $\alpha = 0.05$ significance level performed with G*Power Version 3.1.9.7 (Franz Faul, Universität Kiel, Kiel, Germany) indicated a required sample size of 27 patients.

Overall, 84 patients were included in this study. The patients were divided into three groups according to their vertical facial patterns: hypodivergent (mandibular plane-sella nasion line (MP-SN) $\leq 29°$ or MP-Frankfurt horizontal plane (FH) $\leq 22°$), normodivergent ($29° <$ MP-SN $< 40°$ and $22° <$ MP-FH $< 32°$), and hyper-divergent (MP-SN $\geq 40°$ or MP-FH $\geq 32°$).[15,16] Each group consisted of 28 patients. The study was approved by the Research Ethics Committee of Tianjin Stomatological Hospital (certification number: PH2023-B-016).

The CBCT data of the patients were collected using a KaVo 3D eXam CBCT scanner (KaVo, Germany) at the Department of Radiology of Tianjin Stomatological Hospital. The scanning parameters were: voltage, 120 kV; current, 5 mA; scanning time, 7 s; field of view, 170 mm; voxel size, 0.3 mm. The captured image data were stored in DICOM format and reconstructed in 3D using Dolphin Imaging 11.8 software (Dolphin Imaging and Management Solutions, Chatsworth, California, USA). The slice thickness of the reconstructed images was 0.3 mm.

We constructed the Frankfurt plane using the bilateral orbitale and right porion points.[17] The three-dimensional reconstructed head position was corrected such that the Frankfurt plane was parallel to the horizontal plane, and the head position was recorded as the standard head position (Figure 1). On the axial slice of the CBCT-reconstructed image, the sagittal plane was adjusted using the mesiodistal midpoint of each tooth as the measurement plane (Figure 2).

Measurements were performed in the sagittal plane. The line passing through the tooth and root tips was defined as the long axis (LA) of the tooth, and the vertical line shown in the measurement plane was defined as the VL. The angle between LA and VL was denoted as α, defined as the labiolingual inclination of the tooth. The horizontal line was translated from the

Figure 1. Correction of the head position. Bilateral orbitale and right porion landmarks (red dots) are marked, the axial plane (blue line) in the coronal view was adjusted, and sagittal slices go through the red dots, such that the axial plane on the reconstruction image represents the Frankfurt plane, which is parallel to the horizontal plane.

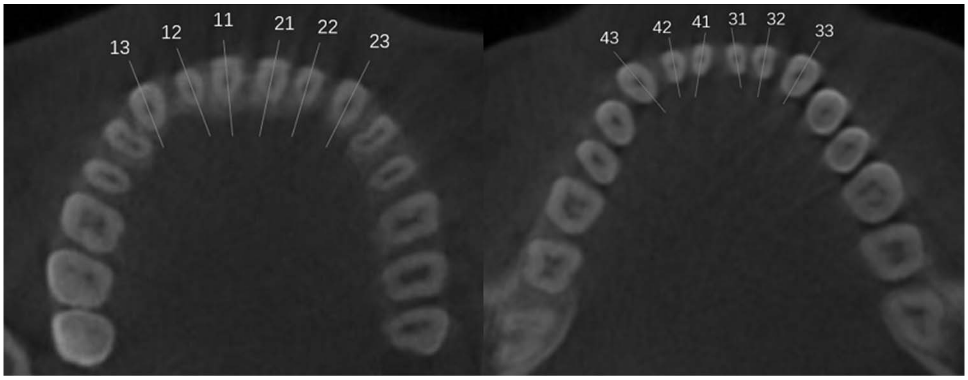

Figure 2. Illustrations of measurement planes for different tooth positions.

root to the crown, and the side where the horizontal line first intersected the alveolar bone crest was defined as point a, and where it intersected the alveolar bone on the opposite side as point b. Points a and b were connected to form a line segment, ab, with its midpoint defined as point c. The horizontal line was moved through the root apex, and the point of intersection of the line with the labiolingual sides of the alveolar bone was defined as points A and B, respectively. Points A and B were connected to form a line segment, AB, with its midpoint named point C. The line passing through C and c was defined as the long axis of the alveolar bone and labeled as AL. The angle between the AL and VL lines, denoted as β, was defined as the labiolingual inclination of the alveolar bone. The angle between LA and AL, denoted as γ, was defined as the dentoalveolar inclination. When LA extended toward the occlusion plane on the lingual and labial sides of AL, γ was negative and positive, respectively (Figure 3).

Statistical Analysis

All measurements were repeated three times at 2-week intervals by the same researcher, and the measurements were subjected to an intragroup correlation coefficient test (ICC $>$ 0.9). The average of the three measurements was used. SPSS 26.0 (IBM, Armonk, NY, USA) was used for statistical analysis. The Shapiro–Wilk test was used to check whether the data distribution was normal. Some data did not follow a normal distribution; therefore, a nonparametric test was adopted, and all data were expressed as medians (P25, P75). The Kruskal-Wallis test was used to compare the labiolingual inclinations of the anterior teeth, corresponding alveolar bone, and dentoalveolar inclination in skeletal Class III patients with different vertical facial patterns. Multiple comparisons between groups were performed using the Bonferroni method. A *P* value $<$.05 was considered statistically significant.

RESULTS

Labiolingual Inclination of the Anterior Teeth

As presented in Table 2, the labiolingual inclination of the mandibular canine in the different vertical facial patterns was significantly different ($P < .05$); the inclination was smaller in hypodivergent patients than in

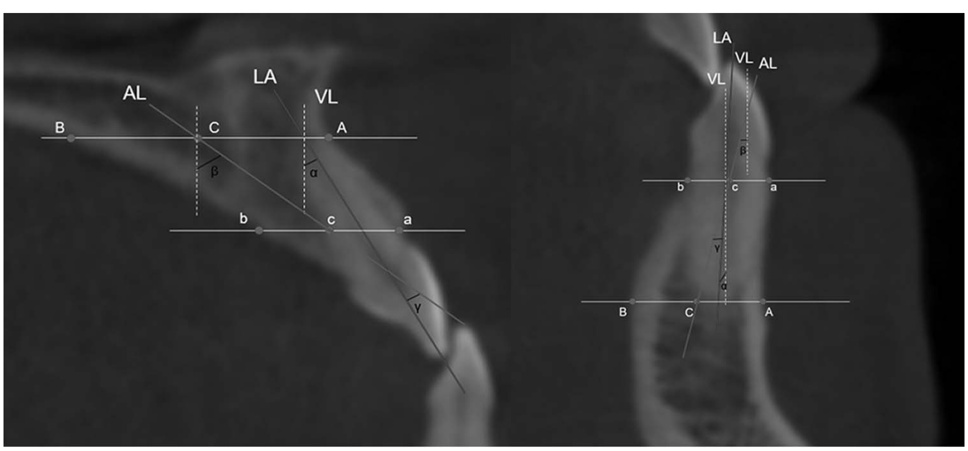

Figure 3. Measurement of the labiolingual inclination of the tooth and corresponding alveolar bone and dentoalveolar inclination.

Table 2. Labiolingual Inclination of Anterior Teeth[b]

Tooth Type	Median (P25, P75)			K–W Test	
	Hypodivergent	Normodivergent	Hyperdivergent	H	P
Maxillary canine	23.400 (19.650, 26.750)	20.800 (16.050, 26.950)	22.400 (18.800, 26.800)	2.037	.361
Maxillary lateral incisor	31.500 (26.750, 38.650)	29.800 (25.025, 35.825)	28.700 (24.250, 33.325)	4.863	.088
Maxillary central incisor	31.850 (25.550, 37.925)	31.800 (23.950, 36.150)	29.100 (23.525, 34.375)	2.565	.277
Mandibular central incisor	14.300 (6.600, 17.900)	16.750 (10.325, 20.375)	15.750 (7.800, 24.500)	5.419	.067
Mandibular lateral incisor	15.850 (8.050, 19.900)	16.600 (12.400, 22.025)	16.450 (10.325, 22.675)	3.239	.198
Mandibular canine	12.300 (4.475, 18.225)[a]	14.500 (10.075, 17.550)[a,b]	16.700 (11.525, 19.925)[b]	7.701	.021*

* Indicates $P < .05$.
[a] Different online letters indicate statistically significant differences.
[b] K–W, Kruskal–Wallis test; P25, 25th percentile; P75, 75th percentile.

hyperdivergent patients. Inclinations of other teeth in the anterior region in the different vertical facial patterns were not significantly different ($P > .05$).

Labiolingual Inclination of the Alveolar Bone

As presented in Table 3, the labiolingual inclinations of the alveolar bone corresponding to the maxillary anterior teeth and mandibular canine in the different vertical facial patterns were significantly different ($P < .05$). Compared with hypo- and normodivergent patients, inclination of the alveolar bone corresponding to the maxillary incisors was smaller in hyperdivergent patients. In hyperdivergent patients, alveolar bone corresponding to the maxillary canines had a smaller inclination than normo- and hypodivergent patients, and inclination of the alveolar bone corresponding to the mandibular canines in hypodivergent patients was the smallest.

Dentoalveolar Inclination

As presented in Table 4, the dentoalveolar inclinations of the maxillary anterior teeth in the different vertical facial patterns were significantly different ($P < .05$). The dentoalveolar inclination in hyperdivergent patients was smaller than that in hypodivergent and normodivergent patients.

DISCUSSION

In 1972, by evaluating 120 nonorthodontic individuals, Andrews summarized and proposed six keys to normal occlusion as ideal targets for orthodontic treatment.[18] However, owing to the limitations of the model analysis, the six keys only emphasized the position of the crown and did not analyze the root position. Orthodontists have long relied on the labiolingual inclination of the crown (the angle between a tangent to the labial clinical crown long axis and the perpendicular line of the occlusion plane) to describe the labiolingual inclination of the teeth.[18–21] Recently, CBCT has become more widely used in orthodontics. Compared to the traditional model analysis and two-dimensional radiography, CBCT can accurately analyze three-dimensional root position and morphology,[22] thereby helping orthodontists evaluate labiolingual inclinations of teeth.

This study found no significant differences in the labiolingual inclination of the anterior teeth, except for the mandibular canines, among skeletal Class III patients with different vertical facial patterns. Previous studies have reported no significant differences in the inclination of the maxillary incisors among patients with different vertical facial patterns,[23,24] which was consistent with the results of the current study. However, some studies reported that the mandibular incisors were more lingually inclined in hyperdivergent patients than in hypo-divergent

Table 3. Labiolingual Inclination of Alveolar Bone Corresponding to Anterior Teeth[b]

Tooth Type	Median (P25, P75)			K–W Test	
	Hypodivergent	Normodivergent	Hyperdivergent	H	P
Maxillary canine	42.600 (39.325, 47.625)[a]	39.300 (32.475, 44.925)[a,b]	36.900 (31.025, 42.900)[b]	15.72	<.001*
Maxillary lateral incisor	45.750 (41.500, 50.975)[a]	44.550 (38.900, 50.150)[a]	38.350 (35.375, 45.125)[b]	23.359	<.001*
Maxillary central incisor	44.200 (41.000, 52.375)[a]	43.500 (39.725, 48.200)[a]	37.350 (32.225, 44.225)[b]	22.184	<.001*
Mandibular central incisor	18.700 (14.875, 24.175)	22.350 (15.475, 26.875)	23.550 (17.175, 27.650)	4.119	.128
Mandibular lateral incisor	19.150 (13.225, 22.925)	21.800 (16.525, 26.475)	22.250 (16.675, 28.400)	5.608	.061
Mandibular canine	11.300 (5.850, 14.575)[a]	15.750 (9.350, 21.500)[b]	17.500 (7.900, 25.575)[b]	12.627	.002*

* Indicates $P < .05$.
[a] Different online letters indicate statistically significant differences.
[b] K–W, Kruskal–Wallis test; P25, 25th percentile; P75, 75th percentile.

Table 4. Dentoalveolar Inclination[b]

Tooth Type	Median (P25, P75)			K–W Test	
	Hypodivergent	Normodivergent	Hyperdivergent	H	*P*
Maxillary canine	−18.850 (−24.475, −14.125)[a]	−18.100 (−24.150, −12.175)[a]	−13.900 (−17.800, −9.950)[b]	15.595	< .001*
Maxillary lateral incisor	−12.900 (−20.625, −8.050)[a]	−12.800 (−17.875, −9.350)[a]	−10.950 (−15.000, −8.025)[b]	6.895	.032*
Maxillary central incisor	−13.200 (−19.500, −8.625)[a]	−12.000 (−14.200, −8.950)[a]	−8.450 (−12.525, −6.350)[b]	20.122	< .001*
Mandibular central incisor	−7.550 (−11.725, −3.875)	−5.900 (−9.550, −1.725)	−5.750 (−9.950, −3.000)	2.495	.287
Mandibular lateral incisor	−4.200 (−11.250, 0.425)	−4.550 (−9.250, −0.050)	−6.950 (−9.675, −3.650)	3.169	.205
Mandibular canine	−0.600 (−8.450, 12.200)	−3.100 (−7.375, 5.150)	−2.200 (−7.975, 5.975)	1.447	.485

* Indicates $P < .05$.
[a] Different online letters indicate statistically significant differences.
[b] K–W, Kruskal–Wallis test; P25, 25th percentile; P75, 75th percentile.

patients,[25,26] which was different from the current study. This may have been because of differences in the measurement methods. Kim et al.[27] reported that, in patients with skeletal Class III malocclusion, the inclination of the mandibular incisors related to the MP was strongly influenced by vertical facial patterns, whereas the inclination related to the horizontal line remained relatively stable. One possible explanation is that the position of the mandibular incisors relative to the SN plane is stable despite inclination of the mandibular plane[28] and, because the MP is steeper in hyperdivergent patients, the angle between the long axis of the mandibular incisors and MP may be smaller.

In addition, CBCT can accurately display the morphology of the alveolar bone, and many studies have measured the alveolar bone thickness in different populations and evaluated the position of the root in the alveolar bone.[14,29–31] However, the selection of measurement planes and indices in different studies was often inconsistent, and accuracy of thickness measurements was greatly affected by CBCT scanning parameters; therefore, there were often great differences among different outcomes reported, making it difficult to generalize research conclusions. Angular measurements can effectively avoid this problem and provide new methods for evaluating dentoalveolar relationships. Gracco et al.[7] and Horiuchi et al.[32] proposed measuring the angle between the incisor, buccal, and lingual cortical axes for evaluating dentoalveolar relationships. However, owing to the irregular morphology of the alveolar bone cortex, ensuring consistency in measurements by different researchers was difficult. This study proposed a method to define the long axis of the alveolar bone and improved the reproducibility of measurements.

Previous studies reported that, in people with normal occlusion, the root apices of the maxillary anterior teeth were located in the labial area of the alveolar bone and that the apices of the mandibular anterior teeth were located roughly in the center of the alveolar bone.[33–35] Results of the current study showed that the long axes of the anterior teeth in skeletal Class III patients generally had a smaller inclination than the corresponding alveolar bone, indicating that the root apices of the anterior teeth were located on the labial side of the alveolar bone. Compared to those of the mandibular anterior teeth, the apices of the maxillary anterior teeth deviated more from the center of the alveolar bone, whereas the root apex positions in hyperdivergent patients were farther away from the labial cortex than those in hypo- and normodivergent patients. This finding has implications for orthodontists when considering the extent of tooth inclination change planned when designing compensatory treatment for patients with skeletal Class III malocclusion. Andrews stated that the teeth should ideally be located at the center of the alveolar bone to facilitate the transmission of chewing force.[36] For skeletal Class III patients, compensatory therapy involves labial flaring of the maxillary anterior teeth and lingual uprighting of the mandibular anterior teeth; however, this process is limited by the alveolar bone. This study showed that the risk during further inclination of the maxillary teeth is relatively low, while the process of lingually uprighting mandibular anterior teeth needs to focus on the risk of contact between the root and cortex. This should be considered when uprighting the mandibular anterior teeth to avoid adverse effects of orthodontic compensatory treatment on the periodontal tissue.

This study had limitations. First, all patients included in the study were Chinese; hence, generalizing the results to non-Chinese individuals would require further investigation. Second, the study described dentoalveolar relationships but did not explore consequent limitations in the range of tooth movement. Finally, severity of malocclusion in the participants was not classified, and patients with severe skeletal Class III malocclusions may present with more severe compensatory characteristics, which may influence conclusions.

CONCLUSIONS

- Inclination of the mandibular canines is smaller in hypodivergent than in hyperdivergent patients with untreated skeletal Class III malocclusion.

- Inclination of the alveolar bone corresponding to the maxillary anterior teeth is larger in hypodivergent than in hyperdivergent patients with untreated skeletal Class III malocclusion, whereas the inclination of the alveolar bone corresponding to the mandibular canine is smaller in hypodivergent patients than in hyperdivergent patients.
- Root apices of the anterior teeth are generally located on the labial side of the alveolar bone, and the dentoalveolar inclination is smaller in hyperdivergent patients than in hypo- or normodivergent patients with untreated skeletal Class III malocclusion.

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